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NAVORD REPORT 4279

A STUDY OF THE BURNING RATE OF BICKFORD FUSE UNDER CONSTANT PRESSURE, TEMPERATURE, AND VOLUME CONDITIONS

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BAC

20 JUNE 1956

DEPARTMENT OF THE NAVY
NAVAL ORDNANCE LABORATORY

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

A STUDY OF THE BURNING RATE OF BICKFORD FUSE UNDER CONSTANT PRESSURE, TEMPERATURE, AND VOLUME CONDITIONS

Prepared by:

Robert J. McHenry
Kenneth N. Boley

ABSTRACT: Results of three studies are reported: (a) the effect of pressure on burning rate of Ensign Bickford time fuse; (b) the effect of temperature on burning rate; and (c) the effect of burning in a closed container on the pressure in the container, and the resulting change of burning rate. Equations which permit prediction of time fuse behavior under various conditions of temperature and pressure are presented.

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

The investigation described in this report was undertaken at the request of the Pyrotechnics Branch of the Engineering Department, and was performed by the Technical Evaluation Department under Task NCL-W3-2a-606-2. Its purpose was to provide information required in the design of delay components for pyrotechnics. The information presented is believed to fulfill this purpose, and to represent a substantial addition to the meager data on this subject. Extension of the study to cover higher pressures and smaller volumes, and to investigate the temperatures produced and their effect on the pressure and burning rate, is desirable. Appreciation is expressed to Charles Q. Adams for his valuable contributions to the accuracy and clarity of the mathematical portions of this report. The opinions and conclusions are those of the Technical Evaluation Department.

W. W. WILBOURNE
Captain, USN
Commander

R. E. HIGHTOWER
By direction

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ILLUSTRATIONS

REFERENCES

(a) MIL-F-18215(NOrd), 23 October 1954
(b) "The Rate of Burning of Fuse as Influenced by Temperature and Pressure", Bureau of Mines Technical Paper 6, by Snelling and Cope, Government Printing Office, 1912.

A STUDY OF THE BURNING RATE OF BICKFORD FUSE UNDER CONSTANT PRESSURE, TEMPERATURE, AND VOLUME CONDITIONS

INTRODUCTION

Material Tested

1. In many of the applications of Ensign Bickford time fuse, the fuse is confined in an airtight container. Upon burning, the fuse evolves gases and heat which cause a pressure rise inside the container. This pressure, in turn, causes an increase in the burning rate of the fuse. This study was conducted to gather data on the interaction of pressure, temperature and burning rate, and to determine the possibility of forecasting the results to be expected under various conditions of fuse confinement. Three types of time fuse were used in all tests. All were plastic coated Ensign Bickford fuse made according to reference (a), except for color code. The types are described in Table 1. The use of the letters A, B, and C to identify each type fuse in the rest of the report is not a standard notation, but is used here for convenience.

Preliminary Data

2. According to reference (a), the burning rate of Bickford fuse should be within 10% of the nominal when burned under ambient conditions. Ten 12" samples of Type A from one lot were burned under ambient conditions, and all times were within 1% of the nominal value of 60 seconds. Ten 12" samples of another lot burned within the range 61.5 ± 1 sec. The burning times of some 12" samples of Type C were 63.4 ± 1 sec., and of Type B, 29.8 ± 1 sec. Similar tests on untreated 12" samples of several lots and types of fuse indicated that within a given lot of fuse, the burning time could be expected to be consistent within approximately ±1 second per foot, and that the burning times for all samples fell within ±10% of the nominal value.

EQUIPMENT AND PROCEDURES

Constant Pressure

3. Low Pressure. For fuse burned at pressures below 100 psig, a pressure vessel with a glass observation port was used. The length of fuse was laid on a metal plate and ignited by means of a fireworks squib. The volume of the vessel was approximately one cubic foot. Air was let in until the Bourdon gage showed the proper pressure. The squib lead was touched to a

45-volt battery and a Standard Electric timer was started manually. The timer was stopped when the spurt of flame appeared at the end of the length of fuse. Originally the pressure was allowed to build up inside the pot and an average pressure was used in calculations. In later tests, the pressure was released as it built up and thereby kept almost constant. In some cases the temperature inside the pot increased to a point which was believed to endanger the strength of the glass port (200°F). In order to prevent this, the intake and exhaust valves were partially opened and adjusted so that the pressure was at the desired level and in dymanic equilibrium. No difference in the burning rate was noted among the three methods.

4. Vacuum. The vacuum work was carried out in the same vessel and in the same manner. The vacuum was obtained with a Duo-Seal vacuum pump. The pressure was kept practically constant by opening and closing the valve leading to the pump. No ballast tank was necessary. The pressure was read on a Bourdon gage. The atmospheric pressure was read periodically on a mercury barometer.

5. High Pressure. The higher pressure tests were performed in a vessel with no observation port. The volume of the vessel was about one cubic foot. The pressure was released as it built up. In place of visual observation, parts (b), (e) and (g) of the pressure bomb (Figure 14) were used as stated in the description of the pressure bomb (paragraph 7). The apparatus was assembled vertically, ignition end up, with the nesting held in proper position by tape.

Constant Temperature

6. These tests were performed in a temperature chamber of dimensions 8' x 8' x 15'. The fuse lengths were ignited by fireworks squibs and timed by a manually operated Standard Electric timer. An operator was within the chamber connecting the squib and length of fuse, and an observer was outside passing in fuse lengths and squibs and operating the timer. Fuse lengths which were held at the test temperature for prolonged periods before burning are referred to as conditioned fuse. For the 160°F test, the fuse was exposed to the 160°F temperature for approximately 24 hours before burning. For the cold tests, the fuse was exposed to the -65°F temperature for 16 hours. The lengths of fuse remaining after completion of the -65°F tests were exposed to an hour of transitional temperatures and an hour at -20°F before burning in a -20°F atmosphere. Those remaining were exposed to a half hour of transitional temperatures and an hour at 0°F before burning in a 0°F atmosphere. To determine the effects of burning

unconditioned fuse in an atmosphere of elevated or reduced temperature, unconditioned lengths of fuse were passed into the chamber and ignited within 30 seconds.

Constant Volume

7. A special pressure bomb was designed and built for this test. This bomb consists of the following parts (see Figure 14):

a. Cylinder length of 12" and inner diameter of 2.5".

b. Nesting of same length designed to hold fuse in center of cylinder.

c. Four 3/4" diameter rods which fit into nesting to decrease volume.

d. Pieces inserted between above rods in order to further reduce volume.

e. Fuse clip to hold squib against fuse length.

f. Ignition end piece with O-ring and insulated Fahnestock clips to connect with squib leads.

g. Terminal end piece with pressure gage tap and spring-loaded fusible link which breaks contact when burned by final spurt of flame from time fuse.

h. Two aluminum cylinders 6" long, 2-1/2" outside diameter, 3/8" inside diameter to reduce volume to a greater extent than is possible using nesting and fillings.

i. Adapters to allow Control Engineering gage (spark-plug thread) and Esterline-Angus gage (1/4" pipe thread) to be used in addition to the Aberdeen gage for which the bomb is tapped.

8. All pressure-time data were obtained with the Esterline-Angus recording pressure gage. The fireworks squib was ignited by a 45-volt battery. The resistance of the fuse cartridge was measured constantly during the burning by an ohmmeter. The heat from the spurt of flame caused a sudden increase in resistance, even when the cartridge did not break. When this change occurred, the observer stopped the timer. The volume of the bomb containing the various pieces was found by pouring from a graduated cylinder enough water to fill it. Table I shows the approximate volumes of various pieces. Volumes shown on the charts and curves are free volumes before insertion of the time fuse.

RESULTS AND CONCLUSIONS

Constant Pressure

9. The burning rate of time fuse was found to be significantly affected by changes in pressure. The burning time vs pressure curve for Type A fuse is shown in Figures 1 and 2. In these curves t is the time in seconds required for burning a 12-inch length of fuse and P is the absolute applied pressure given in PSI. The data are represented by three straight lines according to the equation,

$$\log t = n(\log P) + b$$

$$\log 12 - \log t = \log 12 - n(\log P) - b$$

$$\log \frac{12}{t} = - n(\log P) + (\log 12) - b$$

$$\frac{12}{t} = r = \text{burning rate in inches per second}$$

$$\log r = n \log P + (\log 12) - b \qquad (1)$$

where n is a negative number, i.e. negative slope

$$\log r = n \log P + \log k$$

where $$\log k = (\log 12) - b$$

taking anti-logarithms:

$$r = k P^n \qquad (2)$$

where $$k = \text{anti log } [(\log 12) - b]$$

$$= \text{anti log } (1.079 - b)$$

(b is found by the following method: Using Figure 2, select a point on one of the three straight lines signifying the three ranges and substitute the coordinates of this point into the equation, $\log t = n(\log P) + b$ - where n is the slope of that particular straight line, and calculate b for that straight line.)

In equation (2), r is the burning rate; P, the absolute pressure; n, the slope of the curve in that range; and k, a constant for each range. The constants and the limits for each of the three ranges are shown in Table 2. No fuse would burn at pressures less than 4.95 psia and ignition is uncertain up to about 7 or 8 psia. The curve for fuse Type B is shown in Figure 3. At gage pressures greater than 100 psi, the results became erratic. This inconsistency might result from another pressure effect producing a decrease of free volume between the grains of black powder due to compression of the fuse. Such a decrease in free volume would cause a slower burning rate, according to reference (b). The line through the rest of the points has the equation $r = .107P^{1/2}$ where r is given in inches per second. No regular burning time vs applied pressure curve, such as in Figure 1, was drawn for fuse Types B and C, because the shape of the curve is the same and the log-log curves lend themselves more readily to interpolation, extrapolation, and equation derivation. The curve for fuse C is shown in Figure 4. No measurements were made on fuse C with gage pressures above 100 psi. Because of difficulties encountered in trying to maintain constant pressure at the time this fuse was tested, some of the higher pressures plotted are average values. With pressures above atmospheric, the equation is $r = .04P^{.58}$; below atmospheric, $r = .0198P^{.833}$.

Constant Temperature

10. The effect of temperature on the burning time of fuse was relatively slight in the range tested (Figure 5). The points plotted at 78°F may not be a true representation of the normal burning time of the tested fuse in that the measurements were made at a later date and are subject to uncertainty in the sampling employed and variations in atmospheric pressure. The results of the test on conditioned fuse as compared with unconditioned fuse indicate that the effect of the fuse temperature on burning rate is slight enough that the temperature change experienced by unconditioned fuse upon passing into the chamber is negligible. An examination of the unconditioned fuse data indicates a very slight increase in the burning rate as the surrounding temperature increases. Although it is not definitely known what temperatures are reached within a sealed container, it is assumed in the Constant Volume section of this report that no significant change in burning time is caused by the temperature increase except insofar as it affects pressure.

Constant Volume

11. Pressure Build Up: The pressure developed in a sealed container as a length of fuse burns is shown in Figure 6 for each type of fuse in a 539cc volume and in Figure 7 for fuse Type A in various volumes. In Figures 8 and 9, the same data are represented with the natural logarithm of the absolute pressure plotted as a function of the time. The straight lines obtained on these graphs indicate that

$$t = K(\ln P) + C \qquad (3)$$

when $t = 0$, $P = 14.7$ psi and $C = -2.688K$. Inserting this into equation (3), we obtain

$$t = K(\ln P) - 2.688K \qquad (4)$$

taking antilogs of (4), we obtain

$$P = e^{\frac{t + 2.688K}{K}} \qquad (5)$$

K is a constant for any particular type fuse when burned in a given volume, but it has different values for different volumes (Figure 9). In Table 3, the values of K found from each pressure-time curve are tabulated along with other values which are to be treated below. These values of K are plotted as a function of volume in Figure 10 and as a function of the volume to the two-thirds power in Figure 11. The straight lines drawn in Figure 11 represent the equation

$$K = k'V^{2/3} \qquad (6)$$

where k' is a constant characteristic of each type fuse. The values of k' are as follows: Type A, 0.870; Type B, 0.355; Type C, 0.517.

12. Use of Equations: With this information, we should be able to predict the following for any length of fuse being burned in a sealed container of known volume:

a. What pressure will be developed at any time during burning.

b. What pressure will be developed after any given length of fuse has burned.

c. How long any given fuse length will burn.

Sample calculations using the equations developed above:

$$P = kL^n \qquad (2)$$

$$t = K(\ln P) - 2.688K \qquad (4)$$

$$P = e^{\frac{t + 2.688K}{K}} \qquad (5)$$

$$K = k'V^{2/3} \qquad (6)$$

Twelve inches of Type A fuse are to be burned in a sealed container which has a volume of 587cc. What will be the pressure within the container after 30 seconds? What will be the maximum pressure reached? How long will the fuse burn?

Using equation (6), $K = k'V^{2/3}$, where $k' = 0.870$ and $V = 587$

$$K = 0.870 \times 587^{2/3}$$

$$= 61.0$$

Substituting this value of K into (4), $t = K(\ln P) - 2.688K$,

we obtain
$$30 = 61.0 \ln P - 2.688 \times 61.0$$

$$\ln P = \frac{30 + 2.688 \times 61.0}{61.0}$$

$$\ln P = 3.18$$

taking anti-log, $P = 25$ psia or 10.3 psig after 30 sec.

Again, using equation (4), $t = K(\ln P) - 2.688K$

differentiating,
$$dt = \frac{K}{P}\,dP \qquad \text{(a)}$$

from equation (2), we find r, burning rate, equals $\frac{dL}{dt}$

or
$$r = kP^n = \frac{dL}{dt}$$

$$dt = \frac{dL}{kP^n} \qquad \text{(b)}$$

equating (a) and (b)

$$\frac{dL}{kP^n} = \frac{K}{P}\,dP$$

or
$$\frac{dL}{kK} = \frac{P^n}{P}\,dP$$

$$\frac{dL}{kK} = P^{n-1}dP \qquad \text{(c)}$$

Substituting values of constants into (c), we obtain

$$\frac{dL}{0.0548 \times 61.0} = P^{-1/2}dP$$

integrating, $\int_{14.7}^{P_{max}} \frac{dP}{P^{1/2}} = \int_{0}^{12} \frac{dL}{0.0548 \times 61.0}$

we find, $2(P_{max}^{1/2} - 14.7^{1/2}) = \frac{12}{0.0548 \times 61.0}$

$$P_{max} = (1.795 + 3.835)^2$$

$$= 31.7 \text{ psia}$$

$= 17.0$ psig, max. pressure attained.

Using equation (5), $P = e^{\frac{t + 2.688K}{K}}$

$$P^{1/2} = e^{\frac{t + 2.688K}{2K}}$$

Substituting this value into equation (2) with $k = 0.0548$ and $n = 1/2$

$$r = \frac{dL}{dt} = 0.0548\ P^{1/2}$$

$$\frac{dL}{dt} = 0.0548\ e^{\frac{t + 2.688K}{2K}}$$

rearranging, $\frac{1}{2K} \times \frac{dL}{0.0548} = \frac{1}{2K}\ e^{\frac{t + 2.688K}{2K}}\ dt$

integrating, $\int_{0}^{12} \frac{1}{2K \times 0.0548}\ dL = \int_{0}^{t} e^{\frac{t + 2.688K}{2K}}\ \frac{dt}{2K}$

$$K = 61.0$$

$$\frac{12}{2 \times 61.0 \times 0.0548} = e^{\frac{t + 2.688 \times 61.0}{2 \times 61.0}} - e^{1.344}$$

$$e^{\frac{t + 2.688 \times 61.0}{2 \times 61.0}} = e^{1.344} + \frac{12}{2 \times 61.0 \times 0.0548}$$

taking logs: $\frac{t + 2.688 \times 61.0}{2 \times 61.0} = \ln \left\{ e^{1.344} + \frac{12}{2 \times 61.0 \times 0.0548} \right\}$

$$t = 122 \ln (3.835 + 1.795) - 2.688 \times 61.0$$

$$= 46.8 \text{ seconds.}$$

For calculations involving type A fuse in a small volume, the integral cannot be taken over the entire range because the constant k changes. For example: Twelve inches of type A fuse is being burned in a 116cc sealed container. We wish to find the time of burning and the length of fuse burned when the pressure is 37.2 psia, and the time of burning of the entire length of fuse and the maximum pressure.

When P = 37.2 psia, ln P = 3.62. K' = 0.87 for fuse type A

from $K = K'V^{2/3}$, we find K = 20.7

then using t = K x ln P - K x 2.688

we find t = 19.2 sec (when P = 37.2 psia)

substituting K = 20.7 into $P = e^{\frac{t + 2.688K}{K}}$ (5)

and taking the square root,

$$P^{1/2} = e^{\frac{t + 55.8}{41.4}}$$

substituting this value of $P^{1/2}$ into equation (2), $r = kP^n$

where n = 1/2, we have

$$r = \frac{dL}{dt} = kP^{1/2}$$

for pressures below 37.2 psia, k = 0.0548 so

$$\frac{dL}{dt} = 0.0548\ e^{\frac{t + 55.8}{41.4}}$$

rearranging terms, $\frac{dL}{0.0548} = e^{\frac{t + 55.8}{41.4}}\ dt$

Integrating dt between the limits 0 and 19.2 sec. and dL between the limits 0 and L, we proceed to find the length of fuse burned at 37.2 psia in 19.2 seconds.

$$\int_0^L \frac{1}{0.0548}\ dL = 41.4 \int_0^{19.2} e^{\frac{t + 55.8}{41.4}}\ \frac{dt}{41.4}$$

$$\int_0^L \frac{dL}{41.4 \times 0.0548} = \int_0^{19.2} e^{\frac{t + 55.8}{41.4}}\ \frac{dt}{41.4}$$

$$\frac{L}{41.4 \times 0.0548} = e^{\frac{19.2 + 55.8}{41.4}} - e^{\frac{55.8}{41.4}}$$

$$L = 41.4 \times 0.0548(e^{1.81} - e^{1.35})$$

$$= 5.1 \text{ in.}$$

For pressures between 37.2 psia and 514.7 psia (see Table 2)

$k = 0.0668$ and $n = \frac{2}{5} = 0.4$

$$r = \frac{dL}{dt} = 0.0668\ P^{0.4}$$

from (5) $$P^{0.4} = e^{0.4\left(\frac{t + 55.8}{20.7}\right)}$$

substituting for $P^{0.4}$ $$\frac{dL}{dt} = 0.0668\ e^{0.4\left(\frac{t + 55.8}{20.7}\right)}$$

Rearranging terms and integrating dL from 5.1 to 12 inches and dt from 19.2 sec. to t sec., we shall find the total burning time of the sample in the 116cc container,

$$\int_{5.1}^{12} \frac{dL}{0.0668 \times 51.8} = \int_{19.2}^{t} e^{\frac{t + 55.8}{51.8}} \frac{dt}{51.8}$$

$$\frac{12 - 5.1}{0.0668 \times 51.8} = e^{\frac{t + 55.8}{51.8}} - e^{\frac{19.2 + 55.8}{51.8}}$$

$$e^{\frac{t + 55.8}{51.8}} = e^{1.446} + \frac{6.9}{0.0668 \times 51.8}$$

Taking logarithms, $$\frac{t + 55.8}{51.8} = \ln[e^{1.446} + \frac{6.9}{0.0668 \times 51.8}]$$

$$t + 55.8 = 51.8 \ln(6.16)$$

$$t = 94.4 - 55.8$$

$$= 38.6 \text{ sec.}$$

Using the relationship found above,

$$\int_{14.7}^{P_{max}} P^{n-1} dP = \int_{0}^{12} \frac{dL}{nK} \qquad (c)$$

and the fact that k changes for type A fuse burned in a small volume from 0.0548 to 0.0668 for pressures from 37.2 psia to 514.7 psia (n changes from 1/2 to 2/5), we shall find the maximum pressure produced. Above, we found that 5.1 inches had burned at 37.2 psia; so, to find P_{max} we must have two integrals with limits of 0 to 5.1 in. with k = 0.0548, n = 1/2 and limits of 5.1 to 12 inches with k = 0.0668, n = 2/5.

K = 20.7

$$\int_{14.7}^{P_{max}} P^{n-1}dP = \int_{14.7}^{37.2} P^{1/2-1}dP + \int_{37.2}^{P_{max}} P^{2/5-1}dP$$

$$\int_{0}^{12.0} \frac{dL}{kK} = \int_{0}^{5.1} \frac{dL}{0.0548 \times 20.7} + \int_{5.1}^{12.0} \frac{dL}{0.0668 \times 20.7}$$

setting these two relationships equal to each other,

$$\int_{37.2}^{P_{max}} P^{-3/5}dP = \frac{5.1}{0.0548 \times 20.7} + \frac{12.0 - 5.1}{0.0668 \times 20.7} - \int_{14.7}^{37.2} P^{-1/2}dP$$

$$\frac{5}{2}[P^{2/5}]_{37.2}^{P_{max}} = 4.5 + 4.94 - 2[P^{1/2}]_{14.7}^{37.2}$$

$$\frac{5}{2} P_{max}^{2/5} = 9.44 - 2(6.1 - 3.83) + \frac{5}{2} \times 37.2^{2/5}$$

$$P_{max}^{2/5} = \frac{2}{5}(4.90 + \frac{5}{2} \times 4.246)$$

$$P_{max} = 6.21^{5/2}$$

$$= 96.3 \text{ psia}$$

$$= 81.6 \text{ psig}$$

An alternate method for calculating P_{max} is the use of equation (5), $P = e^{\frac{t + 2.688K}{K}}$, which does not contain k or n. By substituting the values for total burning time t = 38.6 and K = 20.7, we find P_{max} as follows:

$$P = e^{\frac{t + 2.688K}{K}}$$

$$= e^{\frac{38.6 + 2.688 \times 20.7}{20.7}}$$

$$= e^{4.56}$$

$$= 94.632 \text{ psia} = 79.932 \text{ psig}$$

which compares favorably with the value for P_{max} found above.

13. In Table 3, experimental and calculated values of various quantities are tabulated for every successful run. Figure 12 is a graph of measured burning time versus volume. Figure 13 is a graph of experimental maximum pressure versus volume.

RECOMMENDATIONS FOR FURTHER STUDY

14. There are many questions about burning Bickford fuse in a constant volume which have not been touched by this report. Some of these are:

1. What is the temperature time curve for constant volume burning?

2. What is the change in the burning rate at the various temperatures reached if these temperatures are significantly higher than those covered in this report?

3. What quantities of gas are evolved when fuse is burned at various pressures and temperatures, and how do these gases react to temperature changes?

There are other questions which, within certain limits, have been covered by this report, but whose limits may have to be extended. The constant temperature study has already been mentioned as a possibility. A need for work in smaller volumes would also necessitate higher pressure, constant pressure studies. The bomb shown in Figure 14 can easily be adjusted to a smaller volume by placing a piece in each of the end parts. The bomb was designed to withstand at least 5000 psi.

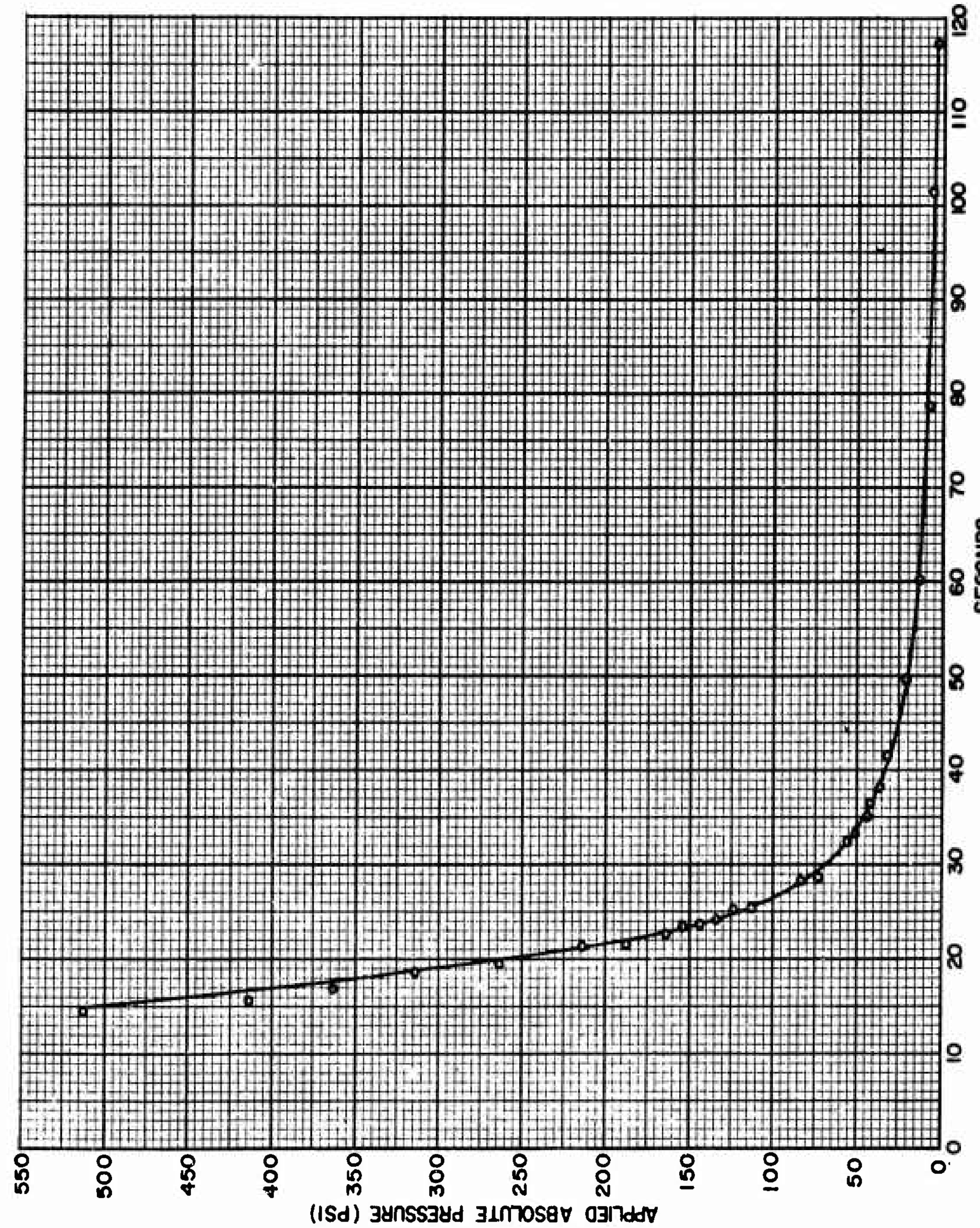

FIG. 1 BURNING TIME FOR A 12 INCH LENGTH OF TYPE A FUSE (60 SEC., 30 GRAIN) vs APPLIED ABSOLUTE PRESSURE

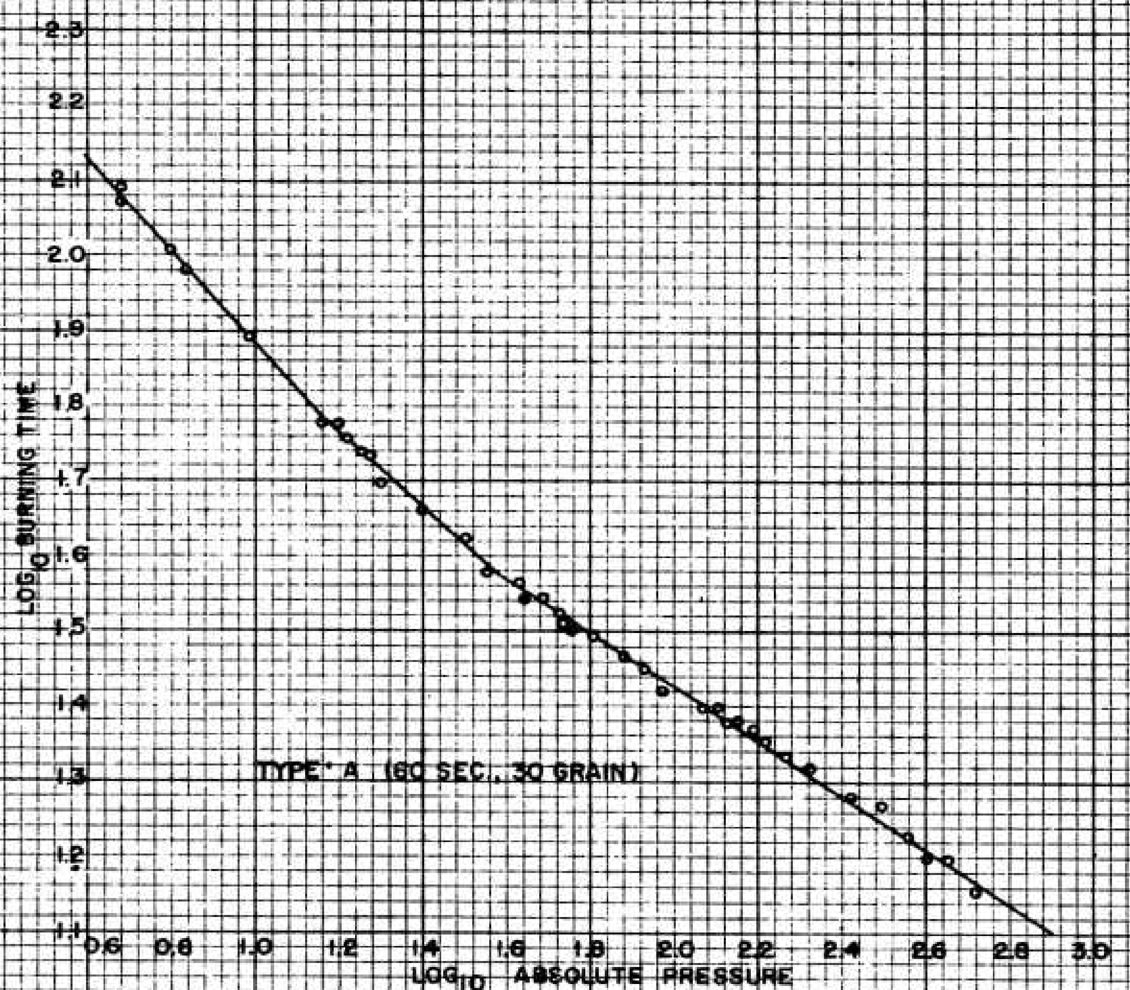

FIG. 2 LOGARITHM OF BURNING TIME OF 12 INCHES OF FUSE vs LOGARITHM OF ABSOLUTE PRESSURE

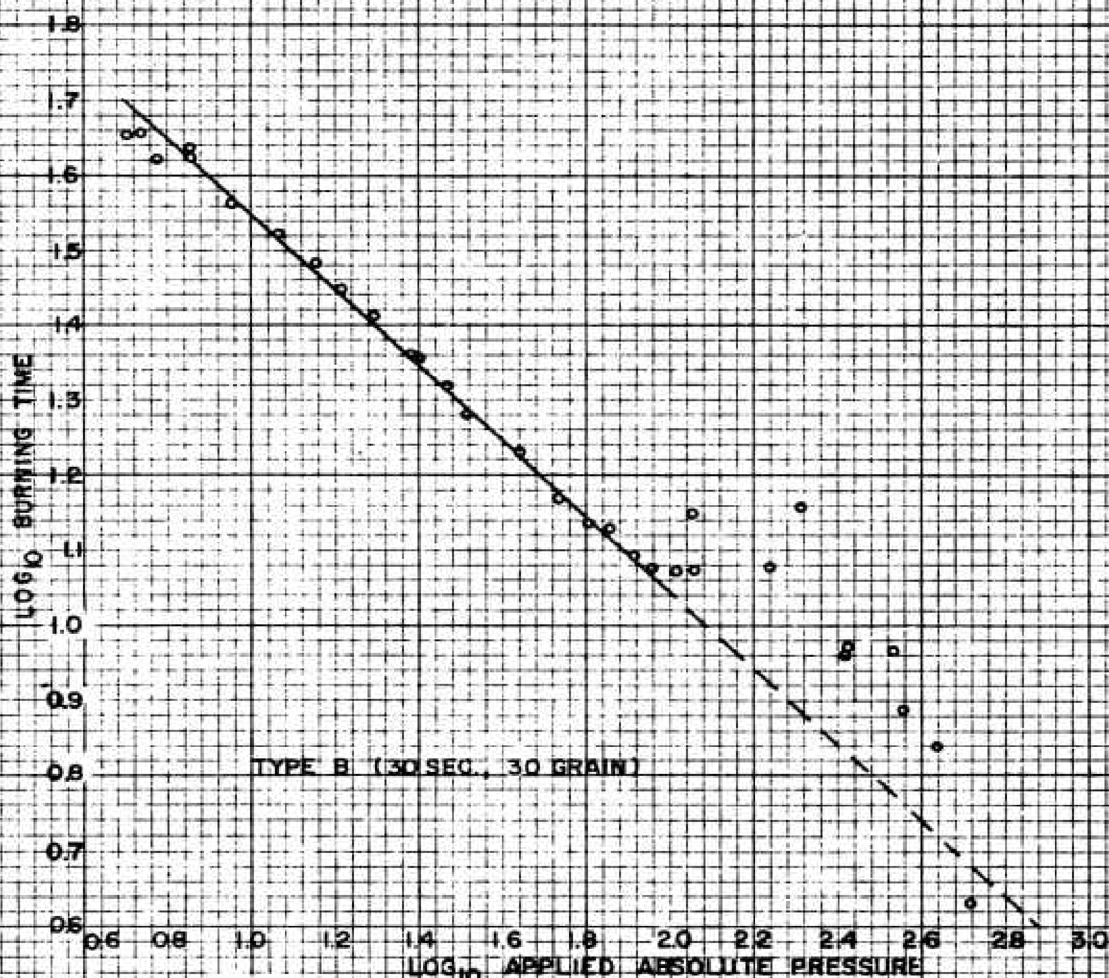

FIG. 3 LOGARITHM OF BURNING TIME OF 12 INCHES OF FUSE vs LOGARITHM OF APPLIED ABSOLUTE PRESSURE

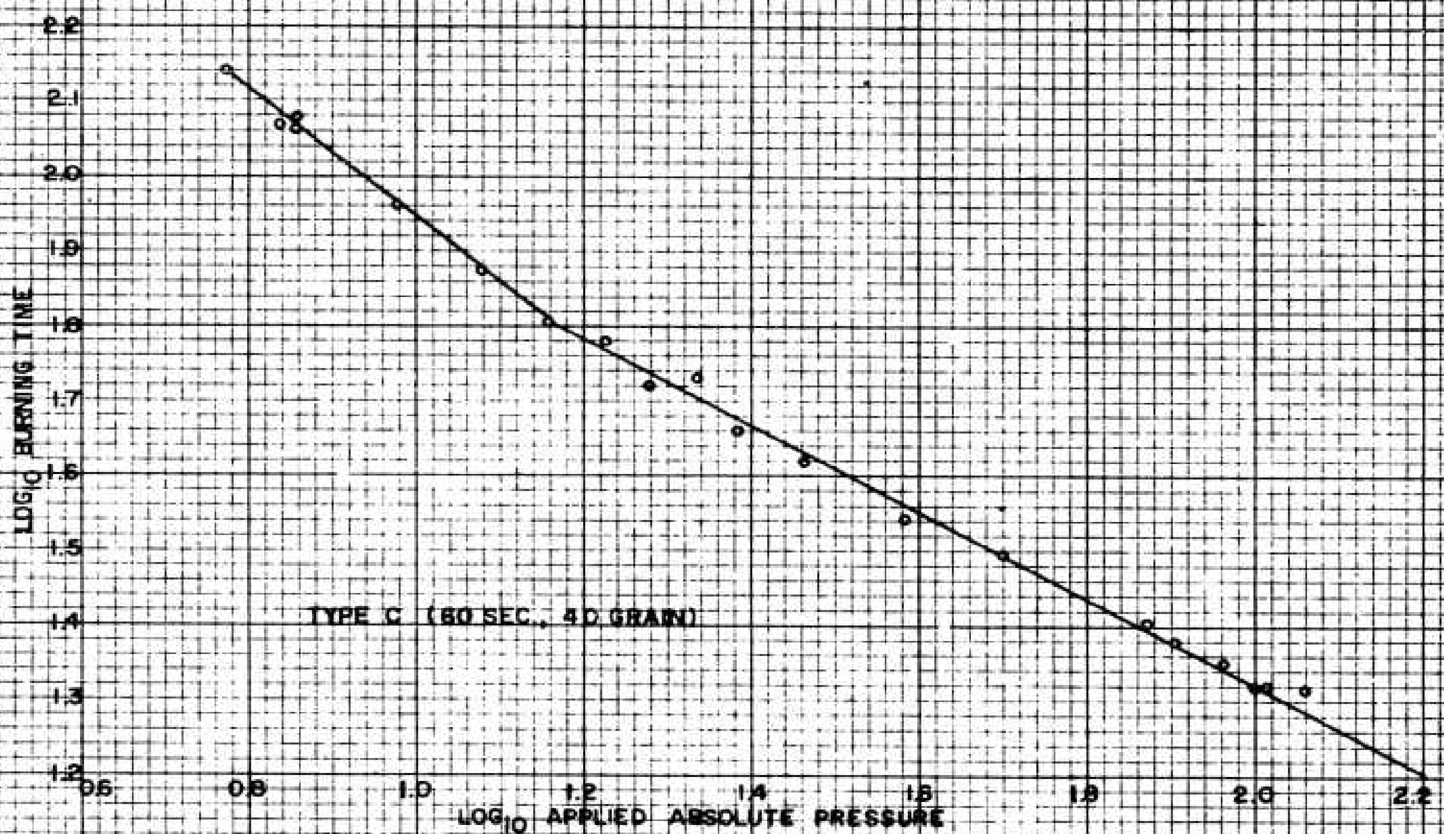

FIG. 4 LOGARITHM OF THE BURNING TIME OF 12 INCHES OF FUSE vs LOGARITHM OF APPLIED ABSOLUTE PRESSURE

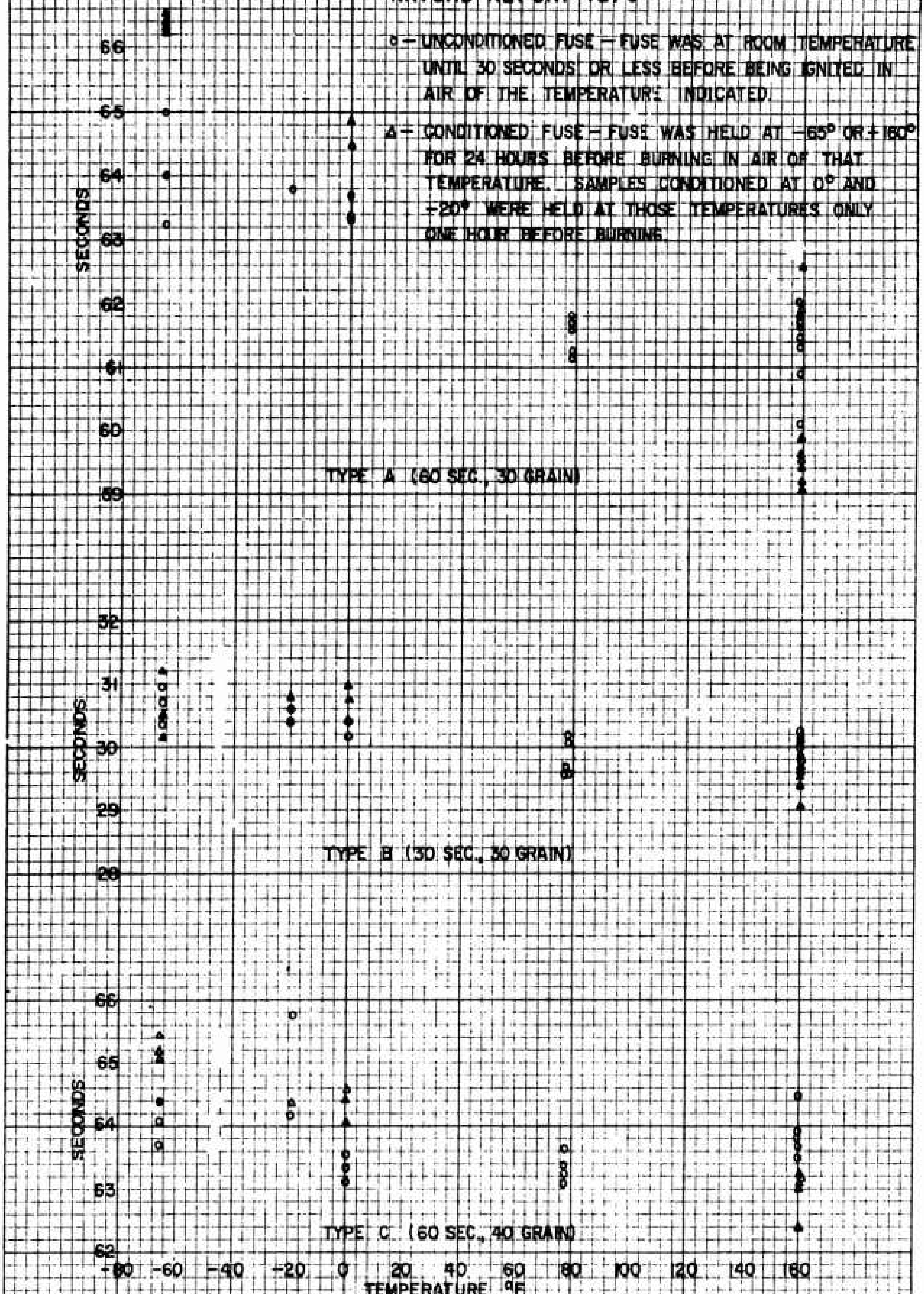

FIG. 5 BURNING TIME FOR A 12 INCH LENGTH OF FUSE vs TEMPERATURE OF ATMOSPHERE

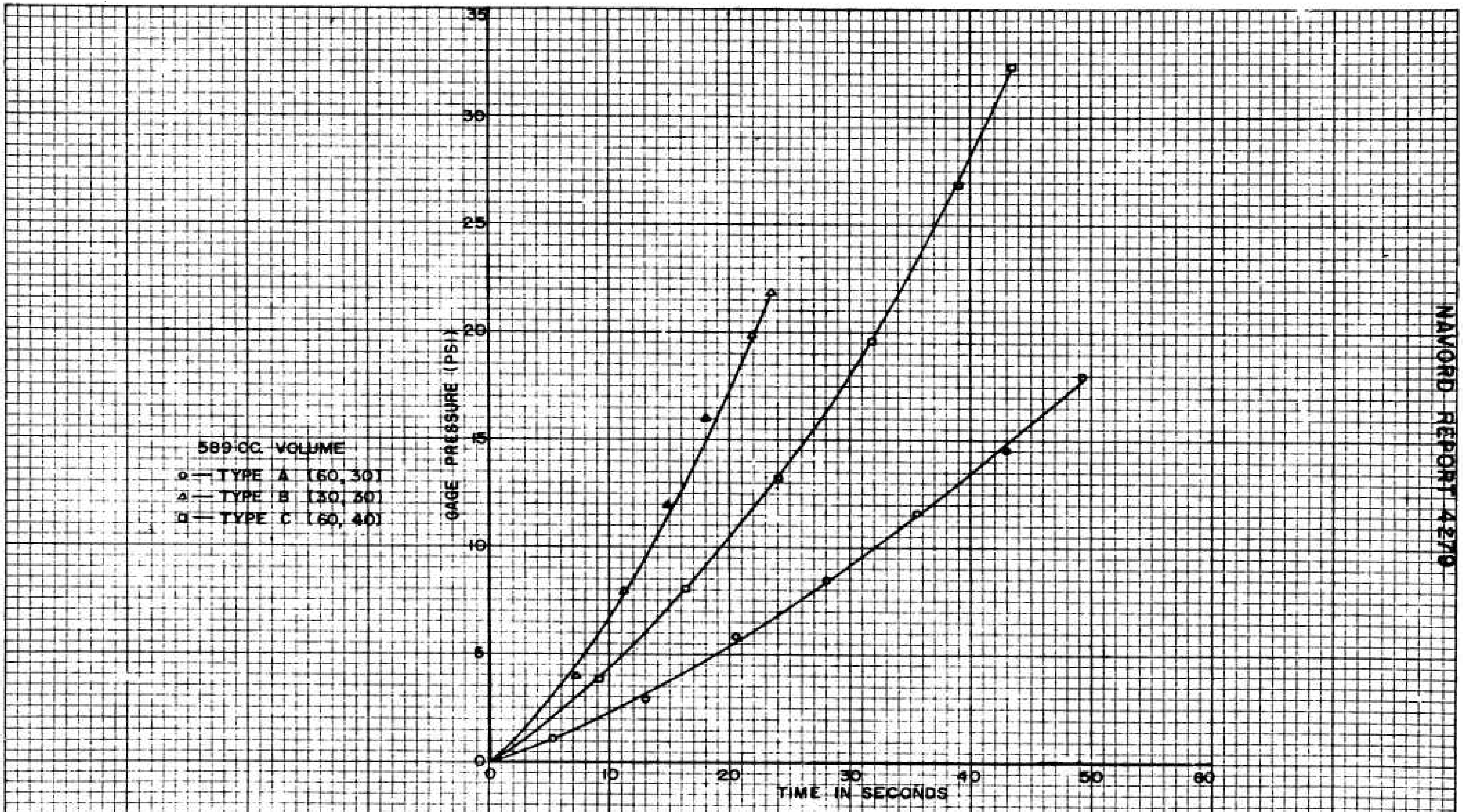

FIG. 6 GAGE PRESSURE DEVELOPED VS TIME ELAPSED SINCE IGNITION

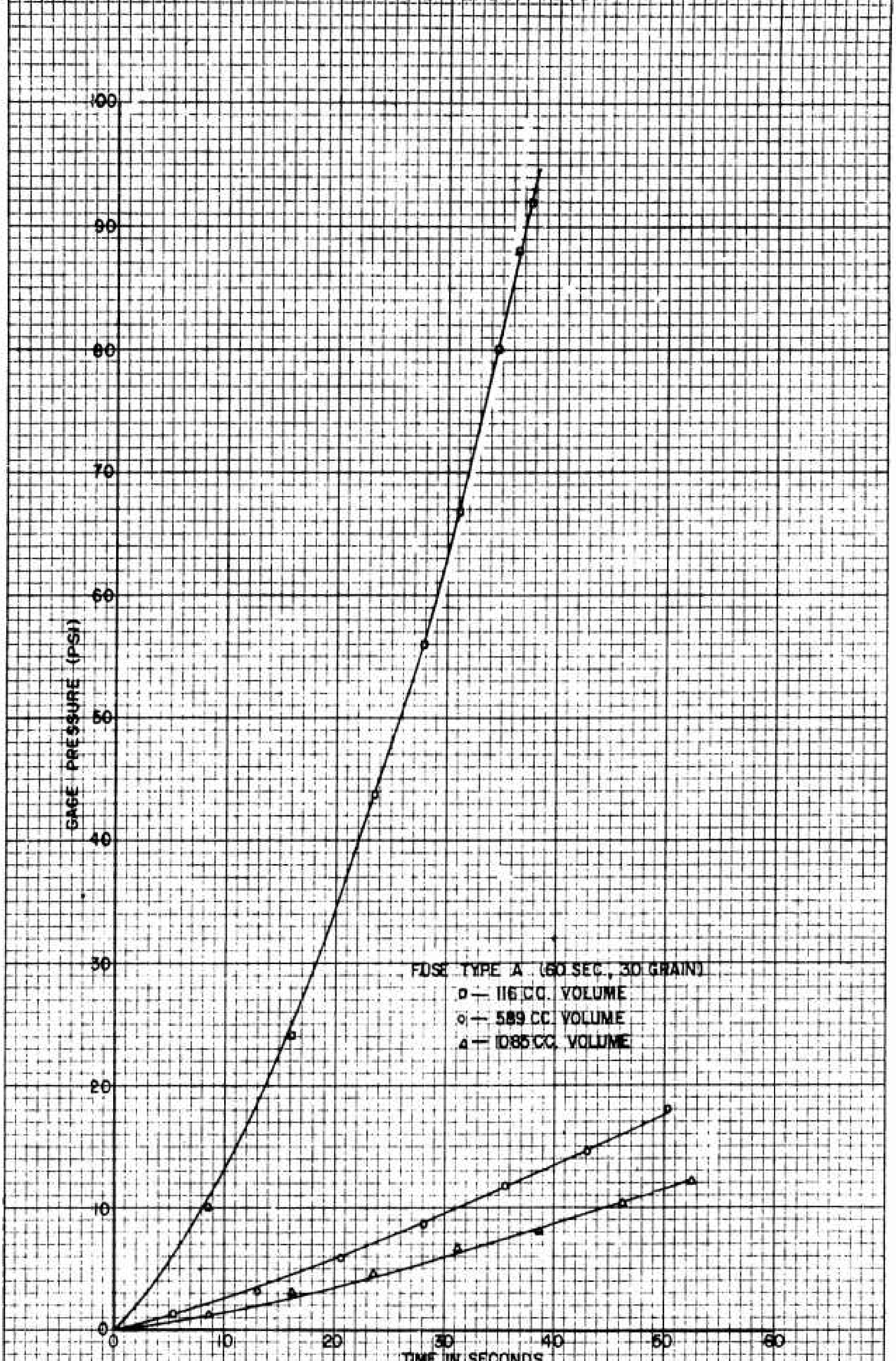

FIG 7 GAGE PRESSURE DEVELOPED vs TIME ELAPSED SINCE IGNITION

NOL - P 34 R
K&E CO., N.Y. 13702

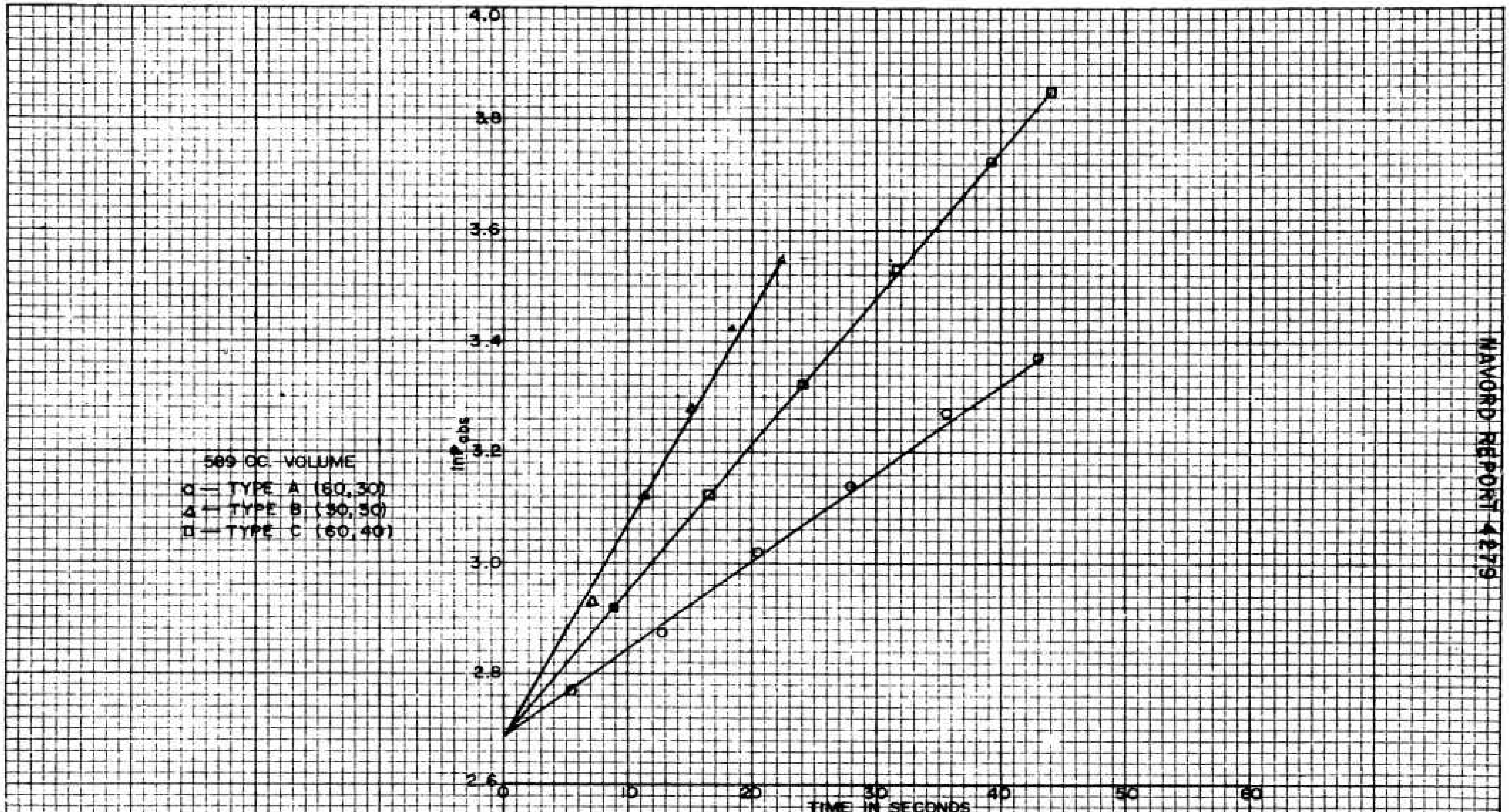

FIG. 8 NATURAL LOGARITHM OF THE ABSOLUTE PRESSURE DEVELOPED VS TIME ELAPSED SINCE IGNITION

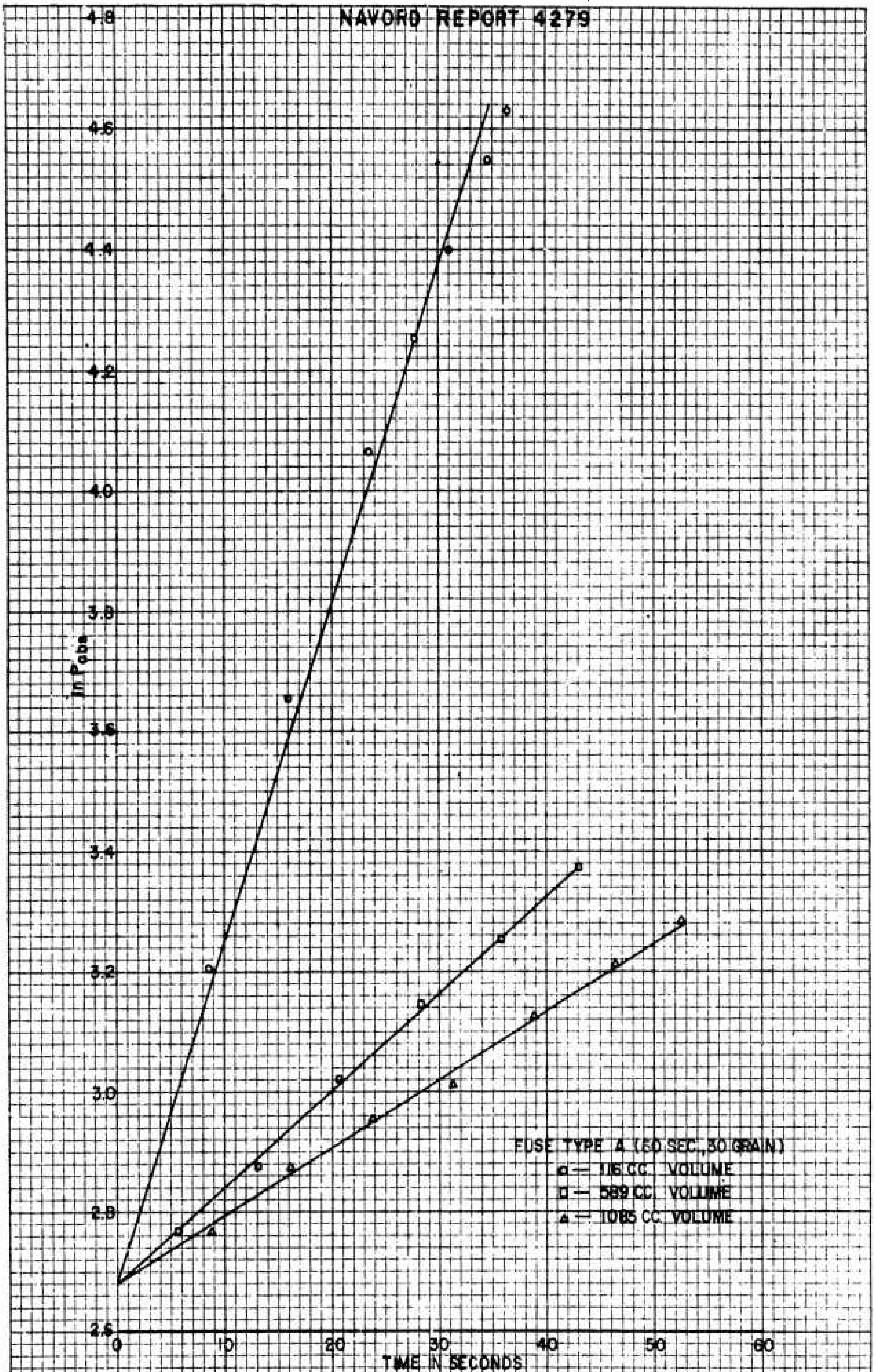

FIG. 9 NATURAL LOGARITHM OF THE ABSOLUTE PRESSURE DEVELOPED vs TIME ELAPSED SINCE IGNITION

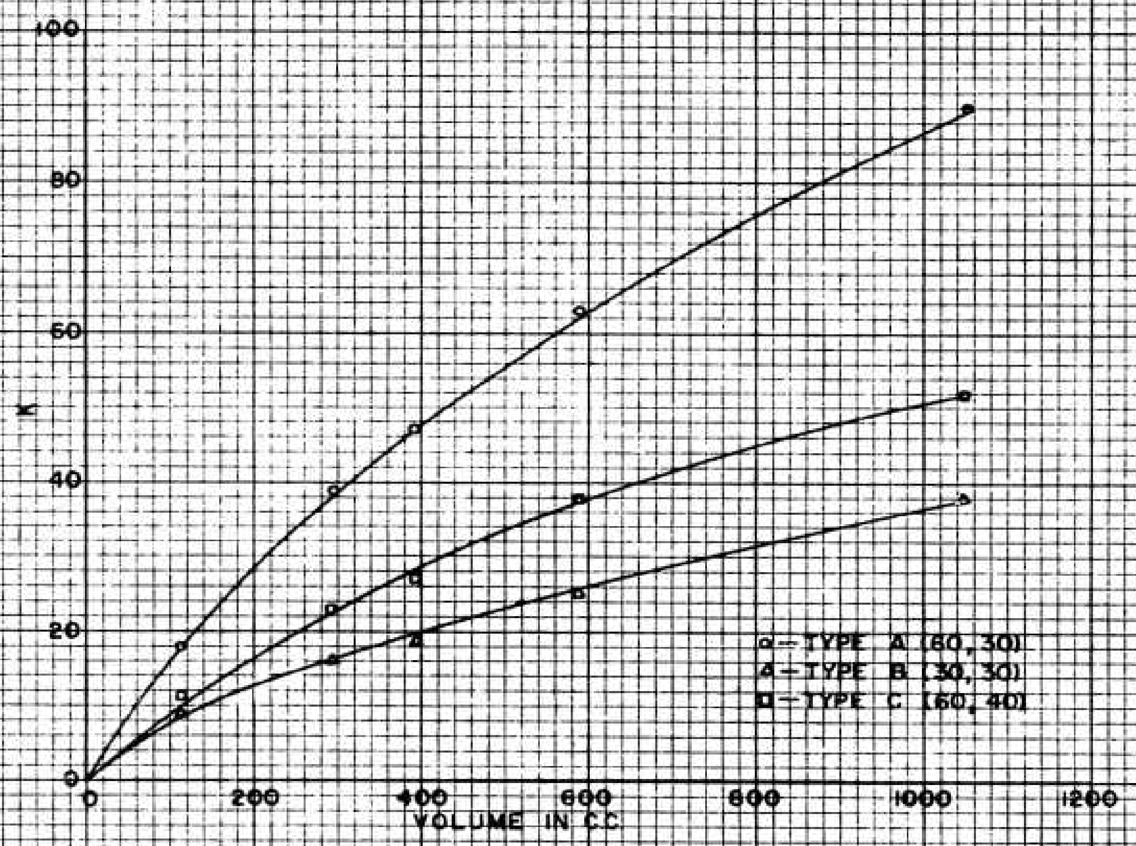

FIG. 10 VALUES OF K vs VOLUME

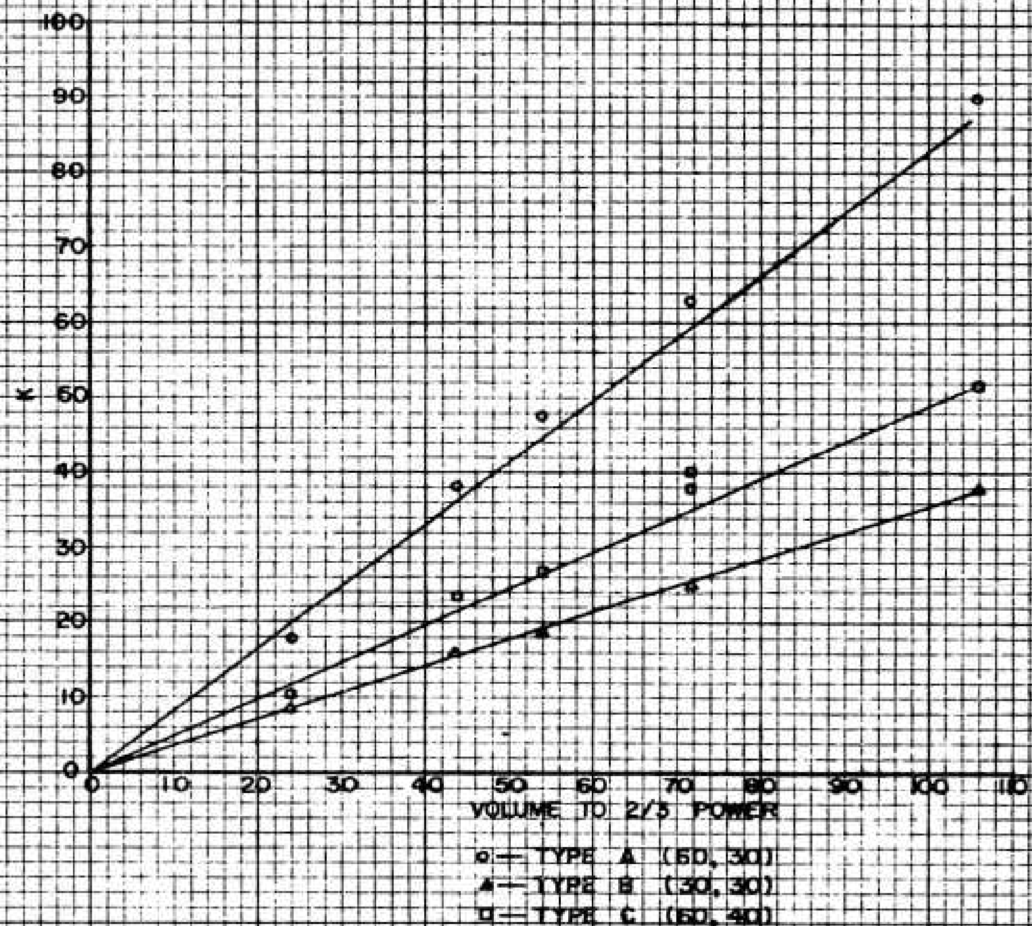

FIG. 11 VALUES OF K vs VOLUME TO 2/3 POWER

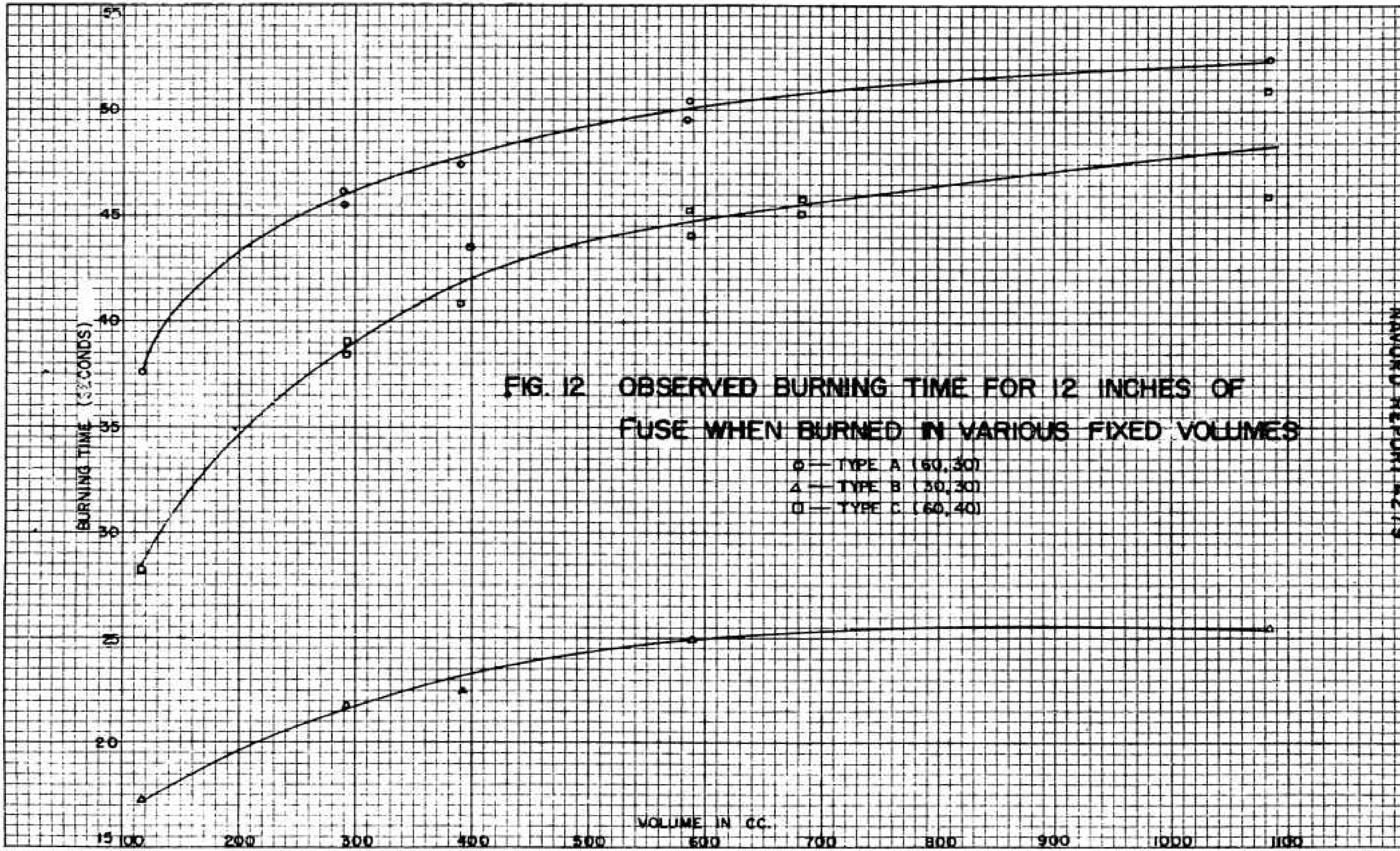

FIG. 12 OBSERVED BURNING TIME FOR 12 INCHES OF FUSE WHEN BURNED IN VARIOUS FIXED VOLUMES

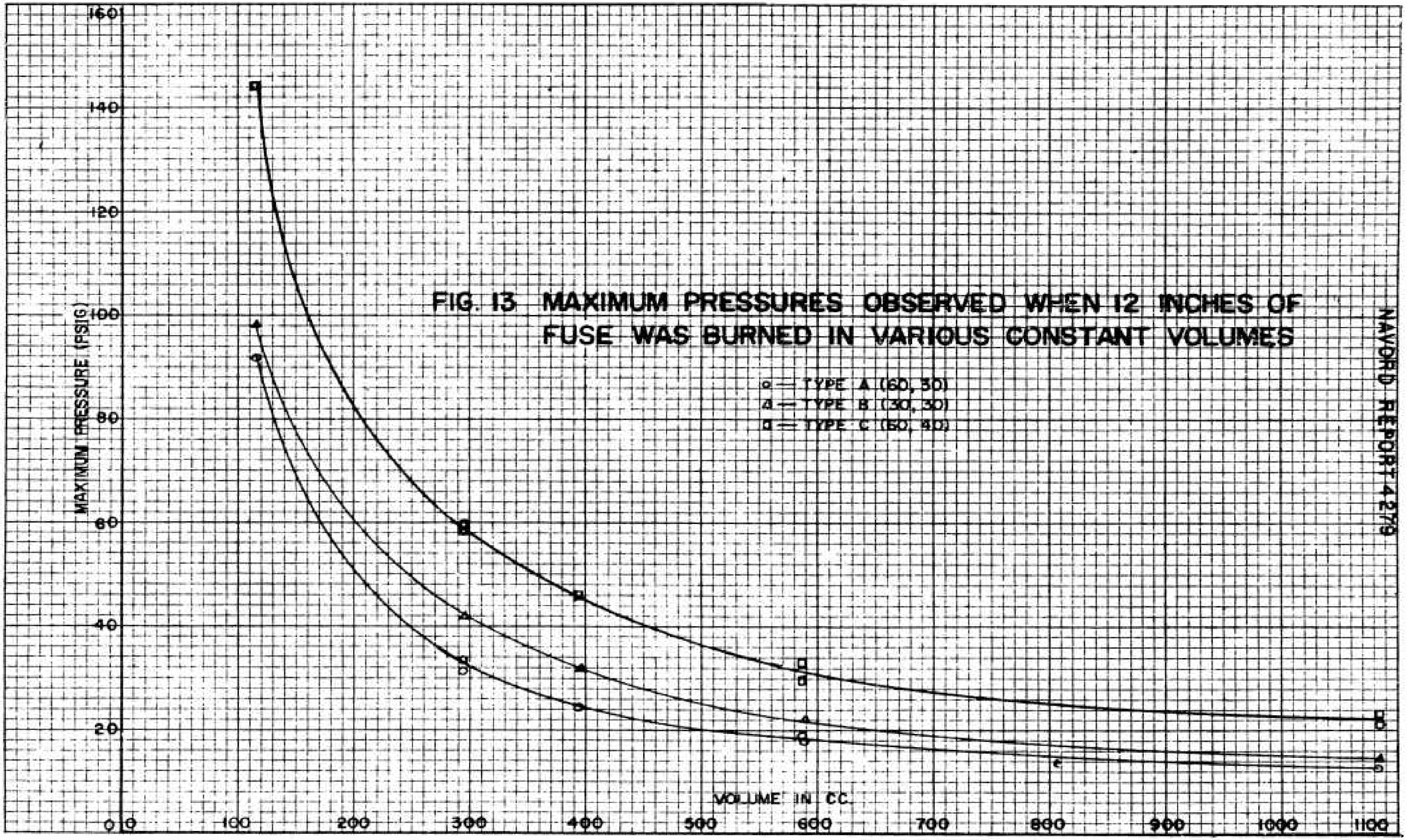

FIG. 13 MAXIMUM PRESSURES OBSERVED WHEN 12 INCHES OF FUSE WAS BURNED IN VARIOUS CONSTANT VOLUMES

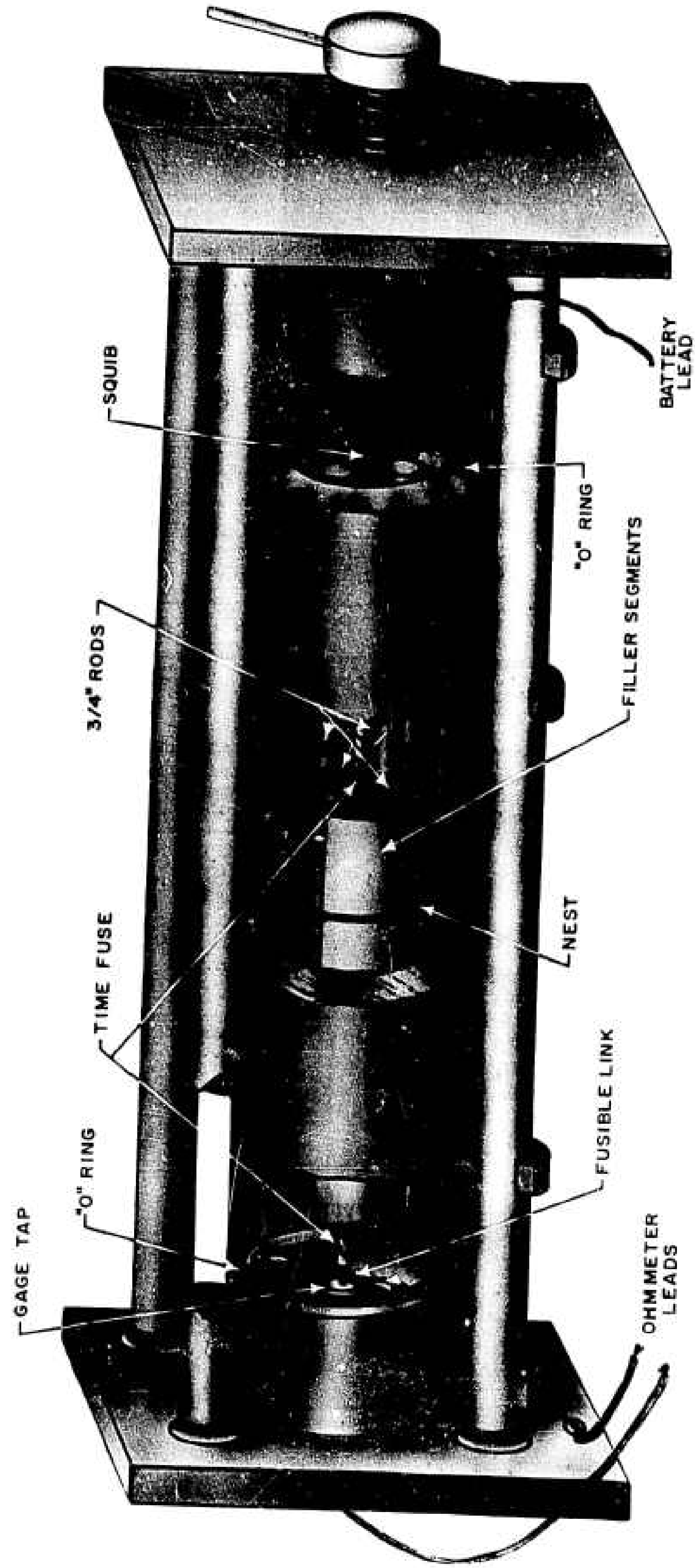

FIG. 14 PRESSURE BOMB FOR CONSTANT VOLUME TESTS

TABLE I

DESCRIPTION OF FUSE TYPES

TYPE	NOMINAL BURNING RATE	NOMINAL GRAINS/FT	COLOR CODE
A	60 SEC/FT	30	GREEN
B	30 SEC/FT	30	RED
C	60 SEC/FT	40	WHITE

TABLE II

RANGE, PSIA	LOG_{10} PSIA	n	K (WHEN r IS IN INCH/SEC)
4.95 TO 14.7	0.695 TO 1.167	3/5	0.0392
14.7 TO 37.2	1.167 TO 1.57	1/2	0.0548
37.2 TO 514.7	1.57 TO 2.712	2/5	0.0668

TABLE III

EXPERIMENTAL AND CALCULATED DATA

* NO P DATA

	VOLUME, CC	MEASURED TIME, SEC.	CALCULATED TIME, SEC.	$K = \frac{1}{SLOPE}$	$K = k'V^{2/3}$ (FIG. 11)	P_{MAX} PSIG MEASURED	P_{MAX} PSIG CALCULATED
TYPE A 60 SEC, 30 GRAIN	1085	52.45	52.80	89.80	91.90	12.5	10.6
	589	50.37	46.80	63.30	61.00	18.0	17.0
	587	49.44	46.80	59.50	61.00	19.0	17.0
	391	47.40	44.20	47.20	46.50	25.0	23.5
	294	46.07	48.75	38.60	38.50	31.5	37.7
	294	45.50	48.75	38.60	38.50	33.5	37.7
	116	37.50	38.60	17.66	20.70	92.0	81.6
TYPE B-30 SEC, 30 GRAIN	1085	25.31	24.70	38.00	37.50	14.5	13.7
	589	24.85	23.08	25.20	24.90	22.0	22.3
	391	22.42	21.64	18.80	18.90	32.0	31.6
	294	21.61	20.68	15.90	15.70	41.0	40.3
	116	17.20	16.97	8.55	8.44	98.0	94.9
TYPE C 60 SEC., 40 GRAIN	1085	50.09	46.40	52.00	54.50	23.0	19.5
	1085	45.80	46.40	52.00	54.50	20.5	19.5
	685	45.73	44.20	*	40.00	*	28.6
	685	44.96	44.20	*	40.00	*	28.6
	589	44.00	42.60	37.80	37.00	32.5	31.5
	587	45.21	42.60	40.00	37.00	29.5	31.5
	400	43.42	39.20	*	28.20	*	44.3
	391	40.73	39.10	27.00	27.50	46.0	46.3
	294	38.30	36.20	22.80	23.00	59.5	56.3
	294	39.00	36.20	22.80	23.00	59.0	56.3
	116	28.20	25.90	10.93	12.10	144.0	110.0

TABLE IV

PART	VOLUME
PRESSURE LINE TO E-A GAGE	+11CC
ENTIRE BOMB WITH NESTING	+1074CC
EACH 3/4" BAR	-100CC
EACH ROW OF PIECES (d)	-98CC
TWO 6 INCH CYLINDERS	-969CC